EN200

LAB #4 PRELAB

INCLINING EXPERIMENT

Instructions

1. The first part of this lab consists of a prelab that covers the theory that will be examined experimentally in this lab.

2. It is to be handed to your instructor at the beginning of the lab period.

3. If you can, answer the questions without referring to your notes. Only refer to them when you are confused or fail to understand a concept. This will greatly improve your understanding of the concepts the lab is designed to reinforce. Remember you will have no notes during quizzes, tests and exams.

4. By conscientiously completing this prelab, you will have a thorough understanding of what the lab is trying to show. Your lab performance will be maximized.

5. All work must be shown on your lab for proper credit. This means that you must show generalized equations, substitution of numbers, units and final answers. Engineering is communication. Work that is neat and shows logical progression is easier to grade.

Student Information

Name: ____________________________

Section: ____________

Date: ____________

Aim:

- Reinforce the students' understanding of the theory behind inclining experiments.
- Provide students with practical experience in conducting an inclining experiment.
- Determine the KG of the 27-B-1 model for future laboratories.

Part 1:Prelab

Apparatus:

1. Figure 1 shows the plan view of a small ship model called the 27-B-1. This model will be inclined to port and starboard by shifting 4 x 0.15 lb weights in several combinations between posts 2, 3, and 4. The resulting moments will incline the ship and the angle of list from each weight shift will be measured with a pendulum assembly.

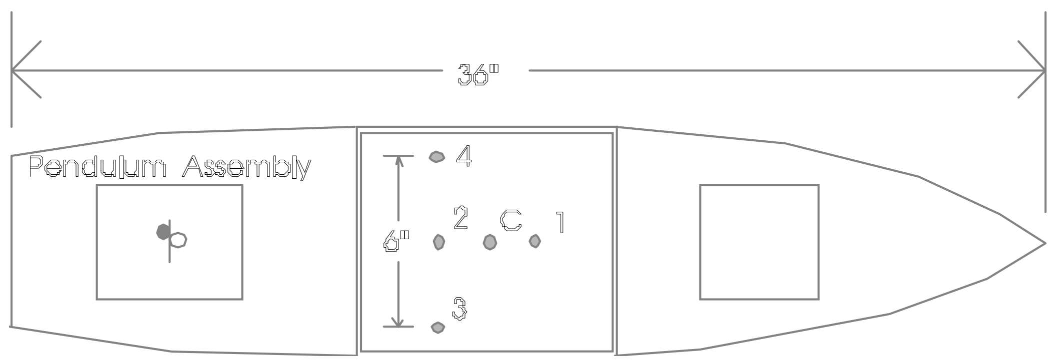


Figure 1 - Plan View of 27-B-1 Model

2. The various posts are named as follows.

Post 1 - Fwd Centerline Post.
Post C - Centerline Post.
Post 2 - Aft Centerline Post.
Post 3 - Starboard Post.
Post 4 - Port Post.

3. Before the inclining experiment can begin and the inclining weights and equipment added, the 27-B-1 model will be in its light-ship condition. This is with the model holding the solid floored tank internally with the solid floor down.

Theory:

4. The major goal of the inclining experiment is to find an accurate value for the vertical height of the center of gravity above the keel (KG). This is performed after a ship has been launched and fully fitted out and after any major refit where it is considered that there may have been a significant alteration to KG.

5. The experiment is conducted alongside the pier, in calm water, and with the ship free to list. The following major steps are then performed.

(i) Light-ship Condition

The Inclining Experiment is usually performed with the ship in its light-ship condition. The light-ship displacement (Δ_{light}) is defined by Gilmer and Johnson as:

> *"the weight of the ship complete in every respect, including hull, machinery, outfit, equipment, water in the boilers at steaming level, and liquids in machinery and piping, but with all tanks and bunkers empty and no crew, passengers, cargo, stores, or ammunition on board."*
>
> *Introduction to Naval Architecture, p131.*

It is necessary to determine the displacement of the light-ship (Δ_{light}). This is achieved by observing the forward and aft draft marks and consulting the ship's curves of form. In this step it is also important to find the density of the water the ship is floating in.

Why is water density important? ____

____

Hint: The curves of form assume sea water @ 59 ^{0} F. The inclining experiment is invariably conducted in port, often close to river estuaries and the water is often contaminated with fuel, spills, etc.

In the box below, show the equation that links the displacement of a ship to the water density it is floating in.

What 2 principles is this equation derived from?

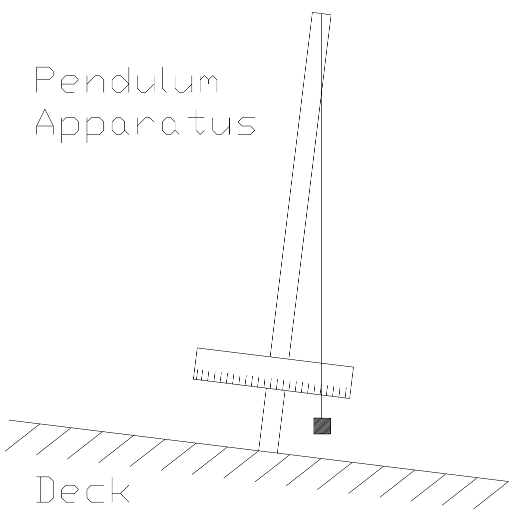
Principle 1 _________________________ Principle 2 ___________________________

(ii) Addition of Inclining Weights and Apparatus

The inclining weights and apparatus are brought on board. Typically, the inclining weights are approximately 2% of the displacement of the light-ship (Δ_{light}). With the inclining weights and apparatus on board, the ship is said to be in an inclined condition. All quantities are then given the inclined suffix. For example Δ_{incl} , KG_{incl} .

In the box below calculate the Long Tons of inclining weights required to conduct an inclining experiment on a DDG51 in its normally loaded condition and then calculate its inclined displacement (Δ_{incl}). Δ_{light} = 6,682 LT

The inclining apparatus consists of a pendulum on a mast that is positioned so that the pendulum is free to swing in the transverse direction. Figure 2 below shows the typical pendulum arrangement. It is used to record the tangent of the inclining angle.



On the Figure show the inclining angle (ϕ) and the adjacent and opposite sides (d_{adj} and d_{opp}) to the triangle that allows the calculation of tan ϕ.

In the box below give the equation for tan ϕ in terms of these quantities

Figure 2 - Inclining Apparatus

For reasons that will become obvious later on, it is also very important to know the height of the center of gravity of the inclining apparatus and weights while they are on the ship.

These distances are often termed $Kg_{pendulum}$ and $Kg_{weights}$ respectively.

(iii) Inclining the Ship

With these stages completed the inclining can then proceed. The theory behind the experiment is evident when considering the diagram of the inclined ship at Figure 3.

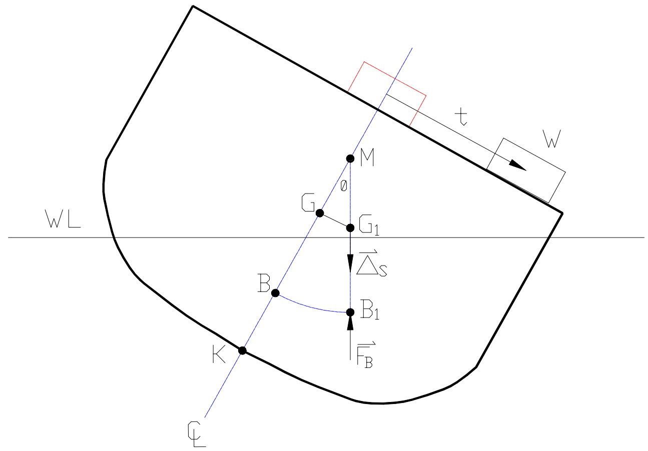


Figure 3 - The Inclining Ship

In the box below, show the geometric relationship between the angle of inclination (ϕ) and the distances GG_1 and GM_{incl}.

The distance GG_1 can also be determined from the weight being shifted (W) and the distance it is moved (t). In the box below show that:

$$GG_1 = \frac{Wt}{\Delta}$$

Hint: GG_1 can be considered as the new TCG of a ship after a transverse weight shift provided the original G was on the centerline.

Combine these 2 equations to find an expression for GM_{incl}.

In practice, the ship is inclined several times with different inclining moments (Wt). At each angle of inclination, the tangent of the inclining angle ($\tan \phi$) is recorded.

A plot is then made of inclining moment (Wt) against $\tan \phi$. This data plots as a straight line and a line of best fit can be placed through this data. The slope of this line can then be determined.

Write an expression for the slope in terms of the measured quantities.

Combine this with the previous expression to find GM_{incl} in terms of the slope of the plot.

(iv) Finding KG_{incl}

With a value for GM_{incl} calculated it is fairly straightforward to determine the distance KG_{incl}.

- On Figure 4, insert the locations of the Keel (K), the center of buoyancy (B), the center of gravity (G) and the transverse metacenter (M). Assume all centroids are on the centerline.
- Also show the distances KM, GM and KG.

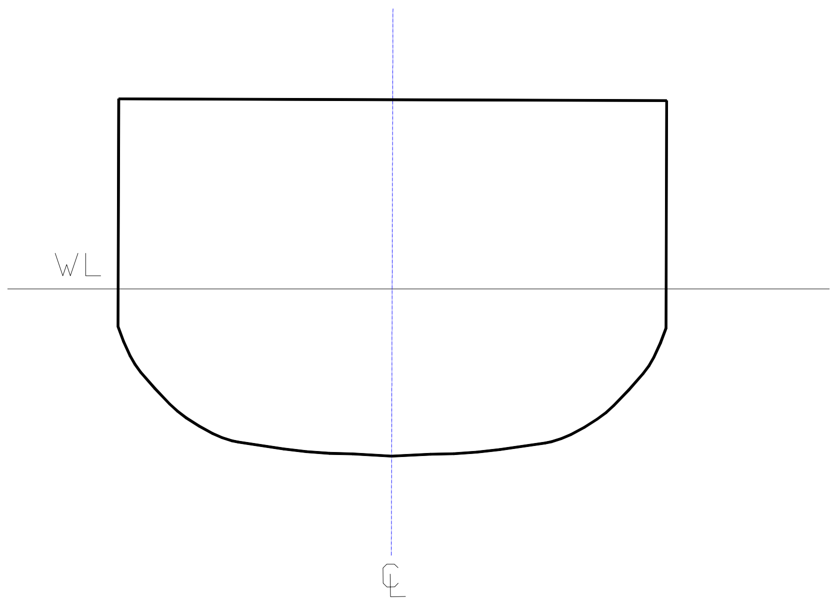


Figure 4 - The Upright Ship

In the box below, use Figure 4 to derive an expression for KG_{incl} in terms of GM_{incl} and KM_{incl}. **Remember, the "incl" suffix simply indicates the ship has the inclining weights and apparatus on board.**

Where would you obtain a value for KM_{incl}? ______________________________________

(v) Removing the Inclining Weights and Apparatus and Finding KG_{light}

The final stage in the experiment is to correct the value of KG_{incl} for the removal of the inclining weights and apparatus to obtain KG_{light}.

In the box give the general expression for the new KG of a ship after the removal or addition or shift of a weight.

This equation can be applied to the removal of the inclining equipment provided the following is known.

$W_{weights}$	-	The weight of the inclining weights.
$Kg_{weights}$	-	The height of the center of gravity of the weights above the keel.
$W_{pendulum}$	-	The weight of the pendulum apparatus.
$Kg_{pendulum}$	-	The height of the center of gravity of the pendulum above the keel.

In the box below apply the general expression with the quantities above and KG_{incl}, Δ_{incl} and Δ_{light} to find the mathematical expression for KG_{light}.

The calculation of KG_{light} is the final goal of the inclining experiment. The height of G above the keel is vitally important in determining the stability characteristics of the ship. This will be demonstrated in future labs.

EN200

LAB 4:

THE INCLINING EXPERIMENT

Instructions

1. This lab is conducted in the hydrolab on the lab deck of Rickover Hall.

2. You will need to bring this lab to the lab period.

3. The lab is to be performed in small groups of 2 or 3 but **each member of the lab group is to submit their own work**. You can ask questions and discuss the content of the lab, but the submitted work must be your own. The lab is designed to provide a valuable learning experience, **copying another persons work will destroy this goal and limit your understanding of the course**.

4. Another way the learning experience of the lab can be destroyed is by failing to **follow the stages of the lab consecutively**. The lab follows a logical thought pattern, jumping ahead without doing the intervening theory questions will limit your understanding.

5. **All work must be shown on your lab for proper credit**. This means that you must show generalized equations, substitution of numbers, units and final answers. Engineering is communication. Other people should be able to understand your work.

6. **This lab is to be submitted at the end of the lab period**. Do not be alarmed if you have not completed the whole lab. It is far better for you to understand the work than rush through it in an attempt to finish. You will not be penalized for an incomplete lab.

Student Information:

Name: ___________________________________ Date: ____________

1st Partner: ____________________________ 2nd Partner: ____________________________

3rd Partner: ____________________________ 4th Partner: ____________________________

Part 2: Procedure

Apparatus

1. Before beginning the experiment, ensure the 27-B-1 model number corresponds with the number on the solid floored tank, the pendulum assembly and the tank. Record the data below - you will need to use the same model in the next 3 EN200 labs.

27-B-1 model number = ______________________

Light-ship Condition

2. The first step is to ensure the model 27-B-1 is in its light-ship condition. This is achieved by the following:

    a. Ensure all detachable weights are off the model (4 x 0.15 lb weights and pendulum apparatus). **Do not** remove the transverse weights used to adjust list.

    b. Ensure there is no loose water within the central compartment.

    c. **Ensure the solid floored tank with its flooded side down is securely installed in the center compartment.**

3. It is necessary to find the weight of the model in its light-ship condition (Δ_{light}). This can be
achieved using two different methods: weigh the model on the scales or calculate the model's displacement by observing the draft marks.

4. Weigh the model and record the following data:

Scale weight of model in its light-ship condition Δ_{light} (lb)	

While the model is out of the water, measure and record the height of the weather deck above the keel:

Height of weather deck above keel (in)	

5. Carefully place the 27-B-1 model in the water. Make sure it is floating freely and is not being inhibited by the tank sides and appendages.

   a. Observe the fwd and aft draft marks on your floating model and fill in the table below.

Light-ship Condition	
T_{aft} (inches)	
T_{fwd} (inches)	
T_M (inches)	
Trim (inches)	

   b. Use the 27-B-1 curves of form at enclosure 2 to calculate the displacement of the 27-B-1 in fresh water @ 59 ^{o}F.

   c. Convert this value into a submerged volume. The density of fresh water @ 59 ^{o}F can be read from the table of data at enclosure 1.

   d. Use the table below to find the true density of the water in the tank.

	Temp (°F)	**ρ (lb-s^2/ft^4)**
Next Lowest Temperature in data		
Tank Water Temperature		
Next Highest Temperature in data		

e. Use this density to calculate the weight of the model in its light-ship condition, Δ_{light}.

6. a. Give 2 reasons why there is a difference between the calculated value and the scale value for Δ_{light}.

Reason 1 ______________________________

____

Reason 2 ______________________________

____

b. Of the 2 figures which do you believe to be the most accurate?

____

Inclined Condition.

7. In this inclining experiment, the inclining weights consist of 4 x 0.15 lb weights. Use the scale to verify the weight of the inclining weights ($W_{weights}$) and the pendulum apparatus ($W_{pendulum}$). Record this data in the table below and calculate the weight of the inclined model (Δ_{incl}).

Displacement in light-ship condition, Δ_{light} (lb) (Step 4)	
Weight of inclining weights, $W_{weights}$ (lb)	
Weight of pendulum apparatus, $W_{pendulum}$ (lb)	
Displacement in inclined condition, Δ_{incl} (lb)	

8. It is very important to know the heights of the centers of gravity of the inclining weights ($Kg_{weights}$) and pendulum apparatus ($Kg_{pendulum}$) above the keel. This information is needed to correct the KG of the inclined model (KG_{incl}) to the KG in its light-ship condition (KG_{light}) when the inclining weights and pendulum apparatus are removed.

   a. Position the inclining weights and pendulum on the 27-B-1 model.

   b. Find the Kg distances by completing the table below.

   Hint: It is much easier to use the weather deck as a vertical reference when calculating these values. It is also a good idea to mark the center of gravity of the pendulum before inserting it into the mast post hole.

Height of weather deck above the keel (in) (Step 5)	
Height of the center of gravity of inclining weights above the weather deck (in)	
Height of the center of gravity of inclining weights above the keel, $\mathbf{Kg_{weights}}$ (in)	
Height of the center of gravity of pendulum apparatus above the weather deck (in)	
Height of the center of gravity of pendulum apparatus above the keel, $\mathbf{Kg_{pendulum}}$ (in)	

9. With this information recorded, you are ready to proceed with the inclining experiment.

   The model should be floating in the tank with the inclining weights on the after centerline post and the pendulum apparatus secure in its stowage near the stern.

   The model is now floating in its **inclined condition**.

   Any list can be corrected by carefully adjusting the location of the weights on the transverse bar until the model floats freely in an upright orientation. For best results, the model should be at zero list.

Inclining the Ship

10. With the ship in its inclined condition, the actual inclining part of the experiment can proceed. You will recall that the pendulum is set up to record the tangent of the inclining angle (Tan ϕ). To do this measure and record the distance d_{adj} below.

    Adjacent length from pendulum apparatus, d_{adj} = ____________________________

11. Carefully move all 4 inclining weights to the port post and begin to complete the results table below. For each weight combination (column 1) ensure you have an accurate reading for the transverse pendulum deflection, d_{opp} (column 5).

Weight Combination	Weight involved in creating the inclining moment **W** (lb)	Moment Arm **t** (in) DOES NOT CHANGE	Inclining Moment **Wt** (in-lb)	Transverse pendulum deflection $\mathbf{d_{opp}}$ (in)	Tangent of the angle of inclination **tan ϕ** (no units)
4 - Port Post 0 - Center Post 0 - Stbd Post					
3 - Port Post 1 - Center Post 0 - Stbd Post					
2 - Port Post 2 - Center Post 0 - Stbd Post					
1 - Port Post 3 - Center Post 0 - Stbd Post					
0 - Port Post 4 - Center Post 0 - Stbd Post					
0 - Port Post 3 - Center Post 1 - Stbd Post					
0 - Port Post 2 - Center Post 2 - Stbd Post					
0 - Port Post 1 - Center Post 3 - Stbd Post					
0 - Port Post 0 - Center Post 4 - Stbd Post					

12. Plot the results of the inclining experiment on the axis in Figure 5. Your plot should be inclining moment (column 4) on the y-axis against the tangent of the inclining angle (column 6) on the x-axis. You may also use a spreadsheet to plot experimental results. **Remember to name and label your plot correctly**.

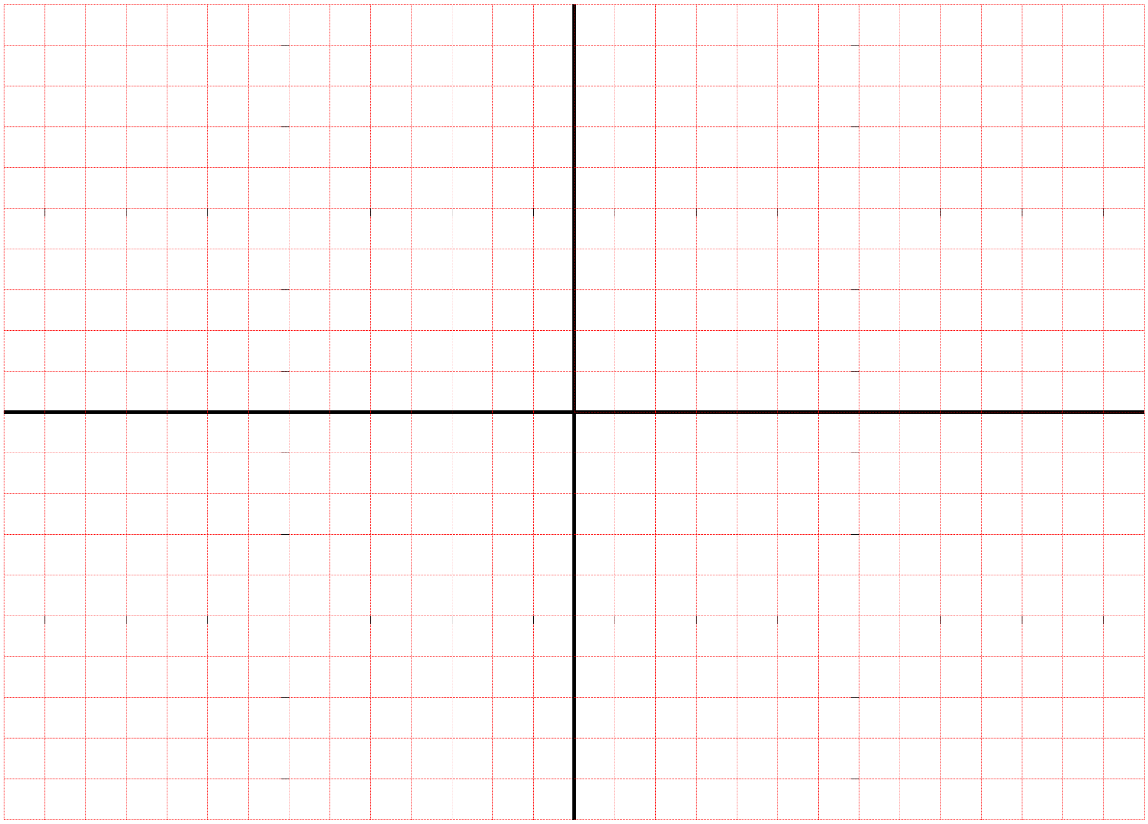


Figure 5 - The Inclining Plot

13. Put a 'line of best fit' through the data points.

    What is the advantage of using multiple results over a single result?

    What is the advantage of using a 'line of best fit' over simply averaging the data?

14. In the pre-lab, you derived 2 equations that can be used to analyze the results of the inclining experiment. They were as follows.

From weight shift theory

$$\overline{GG_1} = \frac{Wt}{\Delta_{incl}} \qquad (equation\ 1)$$

From geometry

$$Tan\ \varphi = \frac{\overline{GG_1}}{GM_{incl}} \qquad (equation\ 2)$$

Show you understand the derivation of equation 2 by completing the inclined ship diagram at Figure 6. Your diagram should include the initial and final centers of buoyancy (B and B1), the initial and final centers of gravity (G and G1), the metacenter (M), the inclining angle (ϕ) and the 2 equal and opposite resultant forces (Δ_S and F_B).

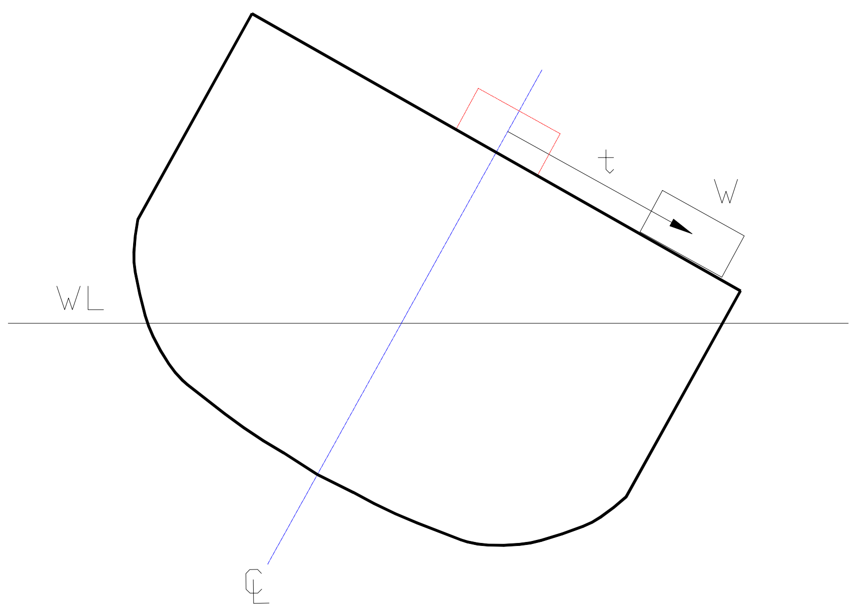


Figure 6 - The Inclined Ship

15. Combine equation 1 and 2 in the box below to give an equation for GM_{incl} in terms of W, t, tan ϕ and Δ_{incl}.

16. Rewrite the equation above incorporating the slope of the inclining plot.

17. Determine the slope of the inclining plot from your data in Figure 5. If you use a linear regression algorithm on a calculator or computer to find the slope, indicate the method used.

Slope = ______________________ =

18. Calculate the metacentric height of the 27-B-1 model in its inclined condition (GM_{incl}).

Determination of KG_{incl}

19. Using the curves of form at enclosure 2, determine KM_{incl}.

20. With the metacentric height of the inclined model (GM_{incl}) found in step (18) it is possible determine the KG of the model in its inclined condition (KG_{incl}) by using the distance from the keel to the metacenter (KM_{incl}) found in step (19). Calculate KG_{incl}. Be sure to show any equations used.

Correcting KG_{incl} for the removal of inclining weights and equipment to find KG_{light}

21. The last step in the inclining experiment is to correct KG_{incl} for the removal of the inclining weights and apparatus to find KG_{light}.

Why is this necessary? ____

____

22. In this instance 2 items are being removed from the model.

a. The inclining weights ($W_{weights}$) a distance $Kg_{weights}$ above the keel.

b. The pendulum apparatus ($W_{pendulum}$) a distance $Kg_{pendulum}$ above the keel.

Write an equation in terms of these quantities to find KG_{light}. Your equation will also include Δ_{light}, Δ_{incl} and KG_{incl}.

23. Insert the values you have recorded earlier and calculate a value for KG_{light}. You will use this value in subsequent labs.

24. Is this value for KG_{light} sensible? Refer to the model when answering this question. ____

Why? ____

____